High-Speed Full-Duplex Multiaccess System for LED-Based Wireless Communications Using Visible Light

Xin LIN, Kenichi IKAWA and Kazutoshi, HIROHASHI
Nakagawa Laboratories, Inc.
Blue Bell Building 5F, 2-15-9 Nishi-Gotanda, Shinagawa-ku, Tokyo 141-0031, Japan

ABSTRACT

An optical wireless full-duplex multiaccess system is described to interconnect a cluster of optical terminals located within the same room using visible light transmission medium. The optical CSMA/CD (carrier sense multiple access with collision detection) method is proposed to ensure the affinity with wire communications such as common Ethernet networks. A bidirectional nondirected access point and a bidirectional directed data terminal are developed to demonstrate the effectiveness of proposed system. The data transmission speed and the communication distance are 100Mbps and about 3m, respectively.

Keywords*:* Optical CSMA/CD method, wireless full-duplex multiaccess, visible-light medium, LED-based communication

1. INTRODUCTION

Optical wireless communications is an advancing field, which has received much attention for local- and personal-area networks. A number of indoor wireless communication systems using infrared radiation have been proposed [1]-[5]. One of major problem in investigating a communications system is how to develop an information environment for low power consumption and ecology. Recently, a method for low energy consumption is proposed by using visible light from an LED illuminator as a medium for wireless digital communications [6, 7].

We are investigating a new full-duplex multiaccess system for LED-based wireless communications using visible light. In this system, an optical access point not only can send and receive data signal for communications, but also is an illuminator for common lifeline. In order to ensure the affinity with popular Ethernet networks, an optical CSMA/CD method is proposed for optical wireless transmission. The effectiveness of this system is demonstrated in a 1-to-n high-speed optical interconnection of 100Mpbs.

2. PRINCPLE OF SYSTEM

The LED-based optical wireless communication system with full duplex and multiaccess is shown in Fig. 1. It consists of one nondirected optical access point with an LED array transmitter and an APD (avalanche photodiode) receiver, and *n* directed optical terminals. A major problem in optical full-duplex method is how to obviate the intersymbol interference between the downlink and the uplink. We have considered and chosen the infrared radiation of 850nm wavelength as a medium for the uplink to differ in the visible light medium on the downlink.

In order to realize bidirectional access, an optical full-duplex CSMA/CD method is proposed to ensure the affinity with the wire LAN communications, as shown in Fig. 2. The CSMA/CD method may be used to provide shared access by a group of attached terminals to the physical medium, which connects the terminals, and data are only sent when no carrier collision is occurred and the physical medium is therefore idle.

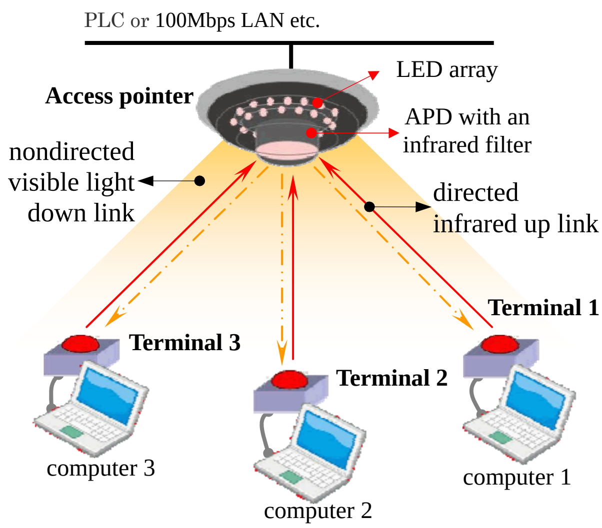

Fig. 1 Schematic diagram of the LED-based optical wireless communication system with full duplex and multiaccess. PLC: power line communications, LAN: local area network.

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Figure 2(a) is optical performance of CSMA/CD for data transmission when no carrier collision. When the computer 1 sends an upload command to terminal 1, the terminal 1 first detects to see if no any carrier is being transmitted by another terminal, and then, upload its data to the access point via line-of-sight infrared radiation. The LED array transmitter on the access point sends an immediate repeat signal via non-line-of-sight visible light after receiving the signal from the terminal 1. All the terminals receive this repeat signal and check if it is consilient with the transmitted signal by itself, and uninterrupted transmission if yes, else, the signal is discarded. On the other hand, because the APD receiver on the access point has a visible-light cut filter in its entrance window, which is adapted to the wavelength of the uplink medium, hence, the interference from downlink can be obviated.

When two terminals receive the upload commands at the same time, and then, they simultaneously try transmission, then will occur a collision. In this case, the access point will send a repeat signal, which has waveform corruption. All the terminals download these corruption signals and tell to their computers to stop upload and await the next command.

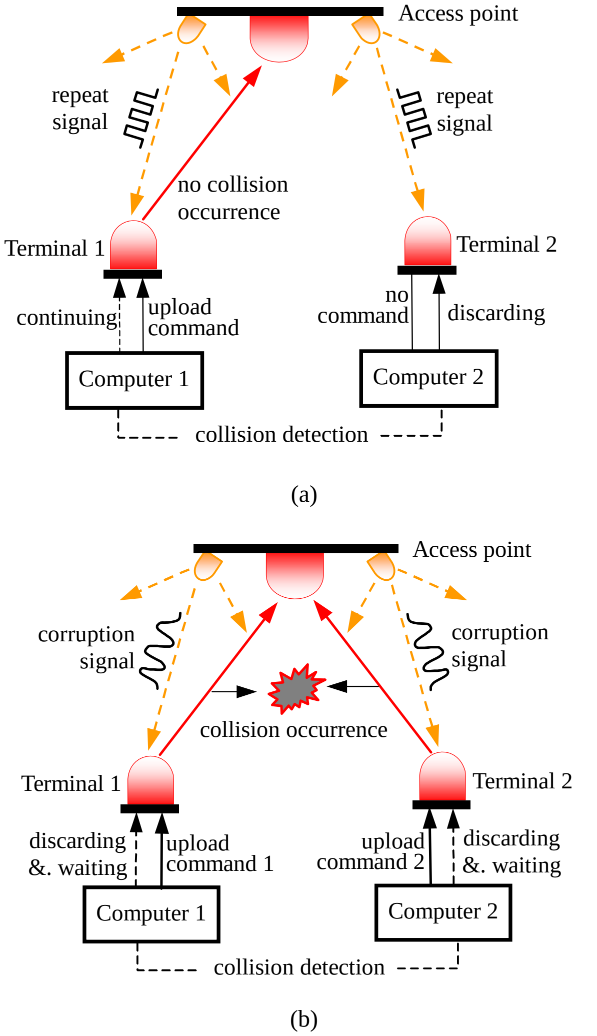

Fig. 2 Principle operation of the optical CSMA/CD: (a) no carrier collision and (b) carrier collision is detected.

3. BIDIRECTIONAL NONDIRECTED OPTICAL ACCESS POINT

I Figure 3 is the developed optical access point. It consists of a visible-light LED transmitter and an infrared APD receiver on its face, as shown in Fig. 3(a), and a control interface on its back is used to connect with a network control board and a console, as shown in Fig. 3(b). The transmitter is a toric LED array. The setting angles of the LEDs for the inner and outer rings are 30 and 45deg, respectively. Thus the service area for communications and illumination can be ensured in a range of 170cm radius when the room and desk (terminal location) height is 250 and 75cm, respectively, as shown in Fig. 4. We have chosen the aluminium material as the chassis of the access point to radiate heat.

In order to make the uplink a high-speed way of 100Mbps, an APD is used as a receiver because it is a high-speed, -sensitivity, and -SNR (signal to noise ratio) photodiode. Although higher dark current and the excess noise due to multiplication are problems in APDs, in general they can provide 3 to 5dB higher sensitivity than *p-i-n* diodes above 100Mbps [8]. The radiation wavelength of the APD receiver is 850nm to adapt to the wavelength of the terminal on the uplink.

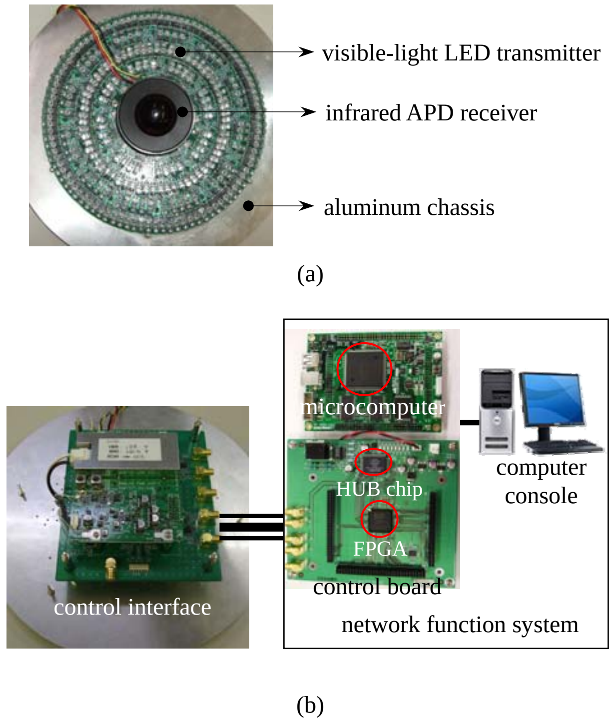

Fig. 3 The optical access point: (a) the transmitter and the receiver on the face, and (b) the control interface on the back and the network function system.

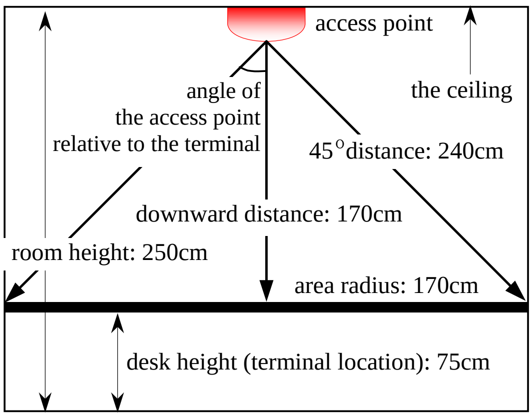

Fig. 4. Geometry used in the indoor service area for communication and illumination.

The control interface board with a voltage amplifier and a bandpass filter to obtaint high SNR when connecting with a network control board to realize the network function.

The network function system consists of a computer console and a control board with a microcomputer, a programmable FPGA (Field Programmable Gate Array) chip and a HUB chip is employed to check the communication state to implement the CSMA/CD operation and realize the network function such as the wire LNA communication.

4. BIDIRECTIONAL DIRECTED DATA TERMINAL

Figure 5 is the developed data terminal with bidirectional access. It consists of an infrared LED transmitter, an infrared APD receiver, which as shown in Fig. 5(a), and a control interface with a sending board (Fig. 5(c)) and receiving board (Fig. 5(d)), which as shown in Fig. 5(b).

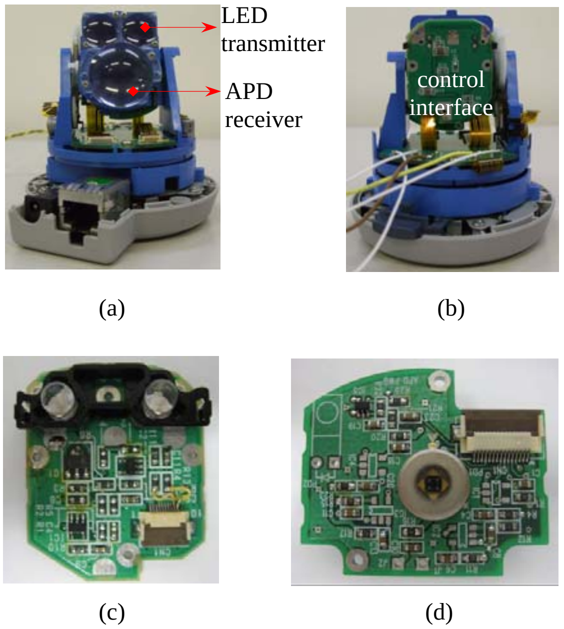

Fig. 5 The data terminal: (a) the transmitter and the receiver on the face, (b) the control interface on the back, (c) the sending board on the control interface, and (d) the receiving board on the control interface.

The transmitter is a pair of LEDs, and each LED has a lens in its radiation window. Hence, the dispersed light from the LED can be focused and becomes the line-of-sight ray for directed data upload. The receiver is an APD, which same with the access point, and also has a lens in its entrance window to realize the directed data download. Similarly, to realize the full-duplex communications with the CSMA/CD method, the terminal also has a network function circuit with the microcomputer, the programmable FPGA chip, and the PHY (Physical Layer) chip, and control computer.

5. EXPERIMENT AND RESULTS

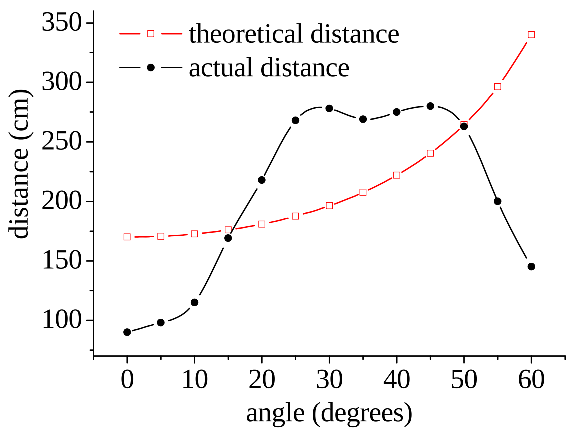

Fig. 6 Dependences of data transmission distance on angles of the optical access point relative to the terminal.

To investigate the communication distance from the access point to the optical terminal, the dependences of data transmission distance on angles of the access point relative to the terminal are measured, and the results are plotted in Fig. 6. The abscissa is the angles, as shown in Fig. 4, and the ordinate is the transmission distance. We can see when the angles from 10deg to 50deg, the actual test distances are larger than the theory calculation distance, and the maximum communication distance is about 3m.

4. CONCLUSIONS

We have described an optical full-duplex CSMA/CD method based on the visible-light LED. By using this method, the 100Mbps high-speed data transmission has been achieved in a 1-to-n multiaccess bidirectional optical wireless communication system. The communication characteristics and quality of this system should be evaluated for further study.

ACKNOWLEDGMENTS

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REFERENCES

[1] F. R. Gfeller and U. Bapst, "Wireless in-house data communication via diffuse infrared radiation", *Proc. of the IEEE* **67**(11), pp. 1474-1486 (1979).

[2] Y. Nakata, J. Kashio, T. Kojima, and T. Noguchi, "In-house wireless communication system using infrared radiation", *Proc. Conf. on Computer Commun*, pp. 333-337 (1984).

[3] H. Hashemi, G. Yung, M. Kavehrad, R. Behbahani, and P. A. Galko, "Indoor propagation measurements at infrared frequencies for wireless local area networks applications", *IEEE Trans. Vehic. Technol.* **43**, pp. 562-576 (1994).

[4] S. Miyamoto and N. Morinaga, "A study on performance improvement of indoor optical wireless communication system", *IEICE Tech. Rep.* MWP98-5, pp. 25-32 (1998).

[5] X. Lin and H. Itoh, "Wireless personal information terminal for indoor spatial optical communication system using a modified DataSlim2", *Opt. Rev.*, Vol. **10**, No. **3**, pp. 155-160 (2003).

[6] S. Haruyama, "Visible light communications," *IEICE Trans.*, Vol. **J68-A**, No. **12**, pp. 1284-1291 (2003).

[7] M. Nakagawa, "Ubiquitous visible light communications," *IEICE Trans.*, Vol. **J88-B**, No. **2**, pp. 351-359 (2005).

[8] A Selvarajan, S Kar, and T Srinivas: *Optical Fiber Communication*, Chap. 5.3, pp. 77-78 (McGraw-Hill, New York, 2002).